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# Hydrogeology of the Kaklik (Denizli) Aquifer in Turkey

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**Abstract**

The purpose of this study is to determine the hydrogeological properties of aquifers, groundwater potential, and hydraulic properties of the Denizli-Kaklık aquifer. The Kaklık aquifer is located at the upper part of the Çuruksu basin covering 1 234 $km^2$ drainage area and is recharged from 3 subbasins; the Yokuşbaşı subbasin (60 $km^2$), the Emirçay subbasin (300 $km^2$) and the Alikurt subbasin (180 $km^2$). Annual precipitation is about $260.4x10^6$ $m^3$/year, evaporation is 183.6 x $10^6$ $m^3$/year, streamflow is $45.57x10^6$ $m^3$/year, discharge from the irrigational wells is 3.3 x $10^6$ $m^3$/year and residual of 27.93 x $10^6$ $m^3$/year is groundwater reserve. The main aquifers are Çökelez Limestone, Sazak formation and Alluvium. The Çökelez Limestone and Sazak formation are karstic aquifers. Malıdağ fm, İnceler fm, Karadere fm and Bayıralan formation are impermeable rocks. The Kızılburun formation is semi-permeable aquifer. Alluvial fan and alluvium are the permeable clastic aquifer. Thickness of aquifer at Yokuşbaşı region varies between 10 to 60 m. Transmissivity contours range between 10 and 24,885 $m^2$/day and hydraulic conductivity contours range between 0 and 120 m/day in Kaklik Aquifer. The water table fluctuations show a decrease of 4 m from 1995 (32 m) to 2003 (36 m). Water table of 42720 wells show an increase from year 1997 to year 2004. Potentiometric surface maps for the years 2008 were constructed for the Kaklık aquifer and it shows the directions of groundwater flow. Potentiometric surface varies from 630 m at Alikurt (east) to 380 m OSM (west) in the flowpath of 20 km. Hydraulic gradient is about h= 0,0125. Flow directions generally incline from east to west.



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*Keywords:* Hydrogeology; karst aquifer; groundwater; hydraulic parameter; water balance;

## 1. Introduction

Kaklık-Denizli semi-karstic aquifer system is located at the intersection point of the Menderes and Gediz graben system in the western part of Turkey. There are eight small catchments in the Upper Çuruksu basin, which are the

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Çaykavuştu (1), Emirçay (2), Alikurt (3), Yokuşbaşı (4), Çökelez (5), Plain (6), Bulancık (7) and Sarıçay (8) subbasins (Figure 1). Drainage areas of these subbasins are in order; 200 km$^2$, 300 km$^2$, 180 km$^2$, 60 km$^2$, 32 km$^2$, 30 km$^2$, 190 km$^2$ and 234 km$^2$ (Table 1). There are 22 springs emerging between the altitude of 315 and 600 m in the upper Çuruksu basin. Largest springs emerge from karstic limestone and the travertine aquifer. The annual average discharge of 21 karst springs in the Çuruksu basin is of 5.2 m$^3$/s. The total annual discharge of these springs is the 163.8 x 10$^6$ m$^3$/year.

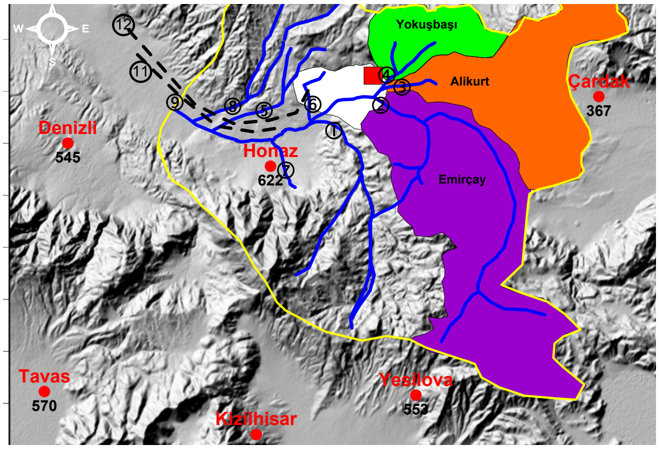


Fig. 1. Location map of Kaklık aquifer and subbasins.

Table 1. Streams, drainage areas, and flows.

| Streams | Drainage area [km$^2$] | Flows [m$^3$/s] | Annual total flows [10$^6$ m$^3$] |
|---|---|---|---|
| 1. Kocaçay | 220 | 0.35 | 11 |
| 2. Emirçay | 300 | 0.20 | 6,3 |
| 3. Alikurt Deresi | 180 | 0.03 | 0.94 |
| 7. Bulancik Çayi | 190 | 0.44 | 13.9 |
| 8. Sariçay | 234 | 0.23 | 7.24 |
| 9. Çürüksu (Böceli Reg.) | 1234 | 3.20 | 100,8 |
| 10. Tekdurmaz Channel | - | 0.75 | 23.62 |
| 11. Kirarki Channel | - | 0.50 | 15.7 |

Table 2. Hydraulic data of Irrigation cooperatives (DSI, 2008).

| No. | Sub-basin | Unit Name | Irrigation land | Wells [m] | Flow rate [l/s] | Quantity [m] | Motopump working time hours/year | Equipment reserve 10$^4$ m$^2$/year |
|---|---|---|---|---|---|---|---|---|
| 64 | 7-15 | KAKLIK | 1500 | 5 | 150 | 750 | 2274 | 1.227 |
| 65 | 7-15 | SAPACA | 2500 | 4 | 160 | 276 | 2348 | 1.352 |
| 66 | 7-15 | YOKUŞBAŞI | 1200 | 5 | 75 | 655 | 2461 | 0.664 |
| | | **TOTAL** | **5200** | **14** | **385** | **1681** | **7083** | **3.243** |
| 67 | 7-15 | KALKINMA KOOP. | 250 | 1 | 25 | 80 | 2136 | 0.192 |
| 68 | 7-15 | KARATEKE | 1250 | 2 | 140 | 278 | 1944 | 0.980 |
| 69 | 7-15 | KIZILYER (I) | 3000 | 5 | 300 | 750 | 2631 | 2.841 |
| 70 | 7-15 | KIZILYER (II) | 2845 | 6 | 300 | 780 | 1996 | 2.037 |
| 71 | 7-15 | KIZILYER (III) | 850 | 2 | 100 | 250 | 2014 | 0.725 |
| 72 | 7-15 | MENTEŞ (I) | 3400 | 6 | 340 | 1100 | 2375 | 2.907 |
| 73 | 7-15 | MENTEŞ(II) | 500 | 2 | 60 | 400 | 1936 | 0.418 |
| 74 | 7-15 | MERKEZ | 3100 | 6 | 276 | 600 | 2441 | 2.425 |
| 75 | 7-15 | OVACIK | 1250 | 2 | 140 | 256 | 1944 | 0.980 |
| | | **TOTAL** | **21645** | **46** | **2006** | **6175** | **26390** | **16.748** |

There are about 46 wells, which were drilled by DSI in the Kaklık aquifer up to 2008 year. The depth of the wells changes between 50 m to 200 m. There are 12 irrigation cooperatives in the Curuksu basin (Tab. 2). The number of productive wells, which are used to irrigation of 21 645 (De) land is about 46. Motopumps are working 26,390 hours/year. The allocation reserve of all irrigation cooperatives is 16.75 x 10$^6$ m$^3$/year. The allocation reserve is in total 3.3 x 10$^6$ m$^3$/year for the Kaklık, Yokuşbaşı and Alikurt cooperatives.

The study area is between the Çardak (950 m asl) and Denizli (428 m asl) rain gage stations. The average annual precipitation values between 1975-2008 years are in order 364.44 mm for Çardak and 555 mm for Denizli. The study area is located on the average 500 mm precipitation level on the normal distribution map of total annual precipitation for Turkey (DMİ, 2008). A simple hydrological water budget method was applied to the basins. This method can be expressed as: $\mathbf{P = ET + Sr + (G_{DW} + G_{DS} + G_{RSV})}$ (Fetter, 2004).

The Kaklık aquifer is located at upper part of the Çuruksu basin (5) covering 1 243 km$^2$ drainage area and is recharged from 3 subbasins: the Yokuşbaşı subbasin (60 km$^2$), Emirçay subbasin (300 km$^2$) and Alikurt subbasin

(180 km$^2$) (Table 3). These three subbasins have a total drainage area of 540 km$^2$. The annual precipitation is about 260.4x10$^6$ m$^3$/year, evaporation is 183.6x10$^6$ m$^3$/year, stream flow is 45.57x10$^6$ m$^3$/year, discharge from the irrigational wells is 3.2 x 10$^6$ m$^3$/year and residual of 27.93 x 10$^6$ m$^3$/year is groundwater reserve. According to DSI record, there were about 30 wells in Kaklık (Upper Curuksu aquifer) at the year 1990. However, the number of wells has increased to 46 productive wells. There are 12 irrigation cooperatives in Kaklık aquifer. The irrigation land, number of wells, flows, and quantities, motopump working time, assignment reserve, and total extraction are given in Table 4. Based on this table, there are 46 wells, 21,645 km$^2$ of irrigation land, 16 748$_x$10$^6$ m$^3$/year assignment reserve and total extraction 4 652$_x$10$^9$ m$^3$/year.

Table 3. Water budget estimation of the subbasins.

| Estimations and basins | Units | Yokuşbaşi basin (1) | Emirçay basin (2) | Alikurt Basin (3) | Yokuşbaşi Emirçay Alikurt (4) | Cürüksu basin (5) (Böceli) |
|---|---|---|---|---|---|---|
| 1- Drainage area (A) | (km$^2$) | 60.00 | 300.00 | 180.00 | 540.00 | 1243.00 |
| 2- Precipitation- (P) isohyetal method | (mm) | 450.00 | 440.00 | 435.00 | 440.00 | 440.00 |
| 3- Precipitation (P) | ($_x$10$^6$m$^3$) | 27.00 | 132.00 | 78.30 | 237.30 | 546.92 |
| 4- Stream flow ($S_R$) | (m$^3$/s) | 0.16 | 0.80 | 0.47 | 1.43 | 3.18 |
| 5- Stream flow | ($_x$10$^6$m$^3$) | 5.15 | 25.20 | 14.95 | 45.30 | 100.80 |
| 6- Evapotranspiration (ET Thorthwait) | (mm) | 340.00 | 340.00 | 340.00 | 340.00 | 340.00 |
| 7- Evapotranspiration (ET) | (x10$^6$ m$^3$) | 20.40 | 61.20 | 61.20 | 183.60 | 422.62 |
| 8- Groundwater discharge from wells $G_{DW}$ | (x10 m$^3$) | 0.70 | 1.20 | 1.20 | 3.30 | 16.75 |
| 10- Groundwater discharge from springs $G_{DW}$ | (x10 m$^3$) | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 |
| 11- Groundwater Reserve $G_{RSW}$ | (m$^3$/s) | 0.02 | 0.03 | 0.03 | 0.16 | 0.21 |
| 12- Groundwater Reserve $G_{RSW}$ | ($_x$10 m$^3$) | 0.75 | 0.95 | 0.95 | 5.10 | 6.75 |
| 13- (Stream flow/ Precipitation) ratio | (%) | 19.09 | 19.09 | 19.09 | 19.09 | 18.43 |
| 14- (Evaporation/ Precipitation) ratio | (%) | 75.56 | 78.16 | 78.16 | 77.37 | 77.27 |
| 15- (Groundwater/ Precipitation) ratio | (%) | 5.35 | 2.75 | 2.75 | 3.54 | 3.61 |
| 16- Demand of E. ON from the $G_{RSW}$ | (m$^3$/s) | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 |
| 17- Demand of E. ON from the $G_{RSW}$ | (10$^6$ m$^3$) | 0.32 | 0.32 | 0.32 | 0.95 | 0.32 |
| 18- Infiltration to the GW Reserve | ($_x$10$^6$ m$^3$) | 0.43 | 0.64 | 0.64 | 4.15 | 6.43 |

Table 1. Production wells in Kaklık aquifer.

| Sub-basin | Cooperatives | Irrigation land (De) | Wells (number) | Flows (liter/sec) | Meters (m) | Motopump working time (hours/year) | Assign. Reserve (10$^6$ m$^3$/ year) | Total Extraction (10$^6$ m$^3$/ year) |
|---|---|---|---|---|---|---|---|---|
| 7-15 | DENİZLİ - HONAZ- KAKLIK | 1500 | 5 | 150 | 750 | 2274 | 1.227 | 341100 |
| 7-15 | DENİZLİ – HONAZ- KALKINMA KO | 250 | 1 | 25 | 80 | 2136 | 0.192 | 53400 |
| 7-15 | DENİZLİ – HONAZ- KARATEKE | 1250 | 2 | 140 | 278 | 1944 | 0.980 | 272160 |
| 7-15 | DENİZLİ – HONAZ- KIZILYER (I) | 3000 | 5 | 300 | 750 | 2631 | 2.841 | 789300 |
| 7-15 | DENİZLİ – HONAZ- KIZILYER (II) | 2845 | 6 | 300 | 780 | 1886 | 2.037 | 565800 |
| 7-15 | DENİZLİ – HONAZ- KIZILYER (III) | 850 | 2 | 100 | 250 | 2014 | 0.725 | 201400 |
| 7-15 | DENİZLİ – HONAZ- MENTEŞ (I) | 3400 | 6 | 340 | 1100 | 2375 | 2.907 | 807500 |
| 7-15 | DENİZLİ – HONAZ- MENTEŞ (II) | 500 | 2 | 60 | 400 | 1936 | 0.418 | 116160 |
| 7-15 | DENİZLİ – HONAZ- MERKEZ | 3100 | 6 | 276 | 600 | 2441 | 2.425 | 673716 |
| 7-15 | DENİZLİ – HONAZ- OVACIK | 1250 | 2 | 140 | 256 | 1944 | 0.980 | 272160 |
| 7-15 | DENİZLİ – HONAZ- SAPACA | 2500 | 4 | 160 | 276 | 2348 | 1.352 | 375680 |
| 7-15 | DENİZLİ – HONAZ- YOKUŞBAŞ | 1200 | 5 | 75 | 655 | 2461 | 0.664 | 184575 |
| | Totally | 21645 | 46 | 2066 | 6175 | 26390 | 16.748 | 4 652 951 |

## 2. Results and discussions

### *2.1. Kaklik aquifer*

The hydrogeological structure of the Denizli-Kaklık groundwater system is largely controlled by the Miocene graben faults (Fig. 2). The primary aquifer rock in the field is the Çökelez Limestone having a secondary permeability represented by a network of joints, fractures, faults and karstic features because of Plio-Quaternary tectonic activities. The Malıdağ formation spreads in a limited area in north and consists of sandstone and shale.

The İnceler formation has a composition of sandstone-siltstone-mudstone. The Karadere formation consists of sandstone-mudstone. The Bayıralan formation consists of sandstone-siltstone. All formations are impervious. The Kızılburun formation containing clay, silt, marl, sandstone and gravel forms poor permeable aquifer. Faulting in the area cause the formation of secondary permeability in the reservoir rocks. Drilling studies confirmed that the groundwater with high discharge are found in areas where faults are dense. The other aquifer is the Sazak formation containing limestone and travertine, overlying the Kızılburun formation and appearing in an area of about 200 km$^2$ in the West of Kaklık cave. The unit is permeable and karstic. Its continuity is broken by lateral lithological variations in the formation. The thickness of limestone in this unit varies and it is transitive into marls and sandstone laterally and vertically. Intensive karstification has developed in the travertine. Nearly all springs, especially the high-yield karst springs, such as the Haydarbaba, Halkabası springs discharge from this karstified unit. Travertine is Karstic and originates from hot waters that emerge from open fissures along the fault zones. Alluvial fan and alluvium are composed of sand-gravel and permeable aquifers (Figure 2). Geological units were placed into five groups and distinguished in a hydrogeological map. According to this, the high permeability defines groundwater containing an aquifer made of pebble-sand and a high yield aquifer. Low permeable detritals describe conglomerate, sandstone and claystone, which are medium yield aquifers. Soluble corresponding to marble, dolomite, and limestone and is good karstic aquifers. Fractured aquifer explains limestone, marl and travertine medium yield Carbonate aquifers. Locally permeable and impermeable represents generally peblestone, sandstone, mudstone, siltstone, claystone, and are mostly impervious (aquitard) rocks. The Sazak formation and travertine are fractured and cracked, which means they are low grade karstic. These form contacts with the Karateke and Çökelez formation along faults with more than 400 m slip. This unit forms the most common aquifer in the area and appears to be a pool area for karstic waters of Çökelez-Honaz and Malıdağı. Discontinues in the outlet form many springs. Travertine covers an area of 200 km$^2$. Due to intense tectonism, fracture joint, crack and faults cause many solution pores to form. The Haydarbaba, Kelkaya and Gemili dudens are excellent examples. The evaluation of flow rates shows little changes. These may arise from a low degree of karstic development. In highly karstic areas, high output is observed in the spring and the output is reduced to low values in the summer (Özler, 1999).

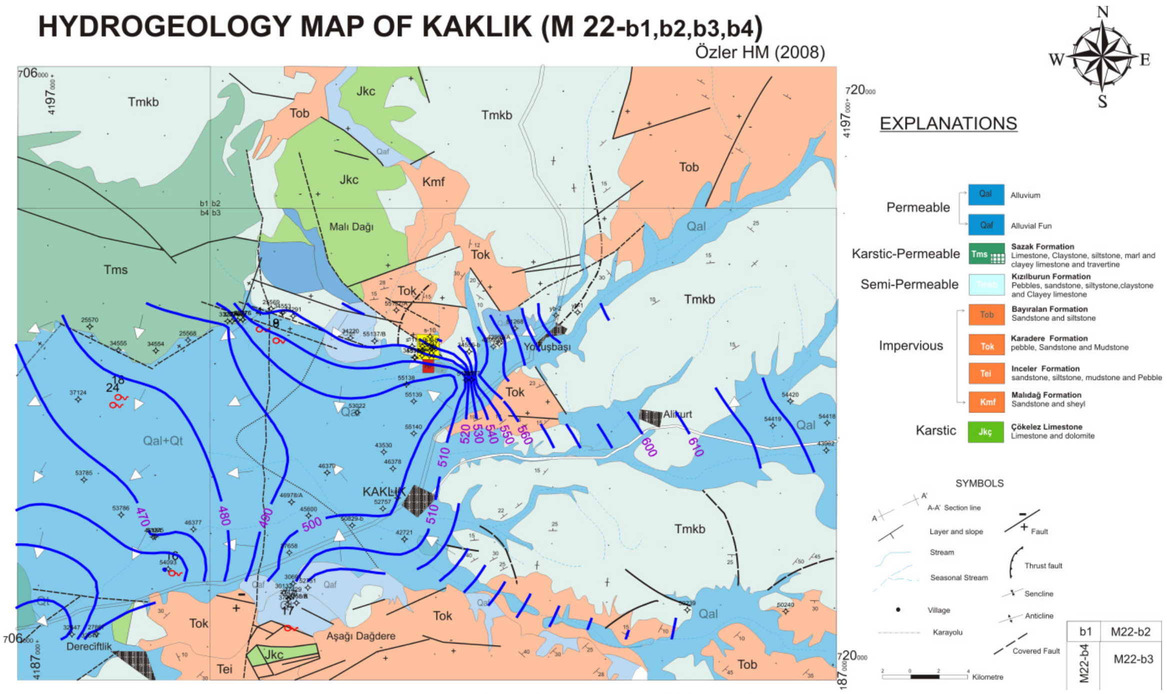


Fig. 2. Hydrogeology map of Kaklık Aquifer.

There are big and important lithological differences (about 200 m) between 34291 and 34220 in Figure 2 and Figure 3. These differences must be because of big graben faults in the system. These two faults zones are the border of good quality of groundwater at the same time.

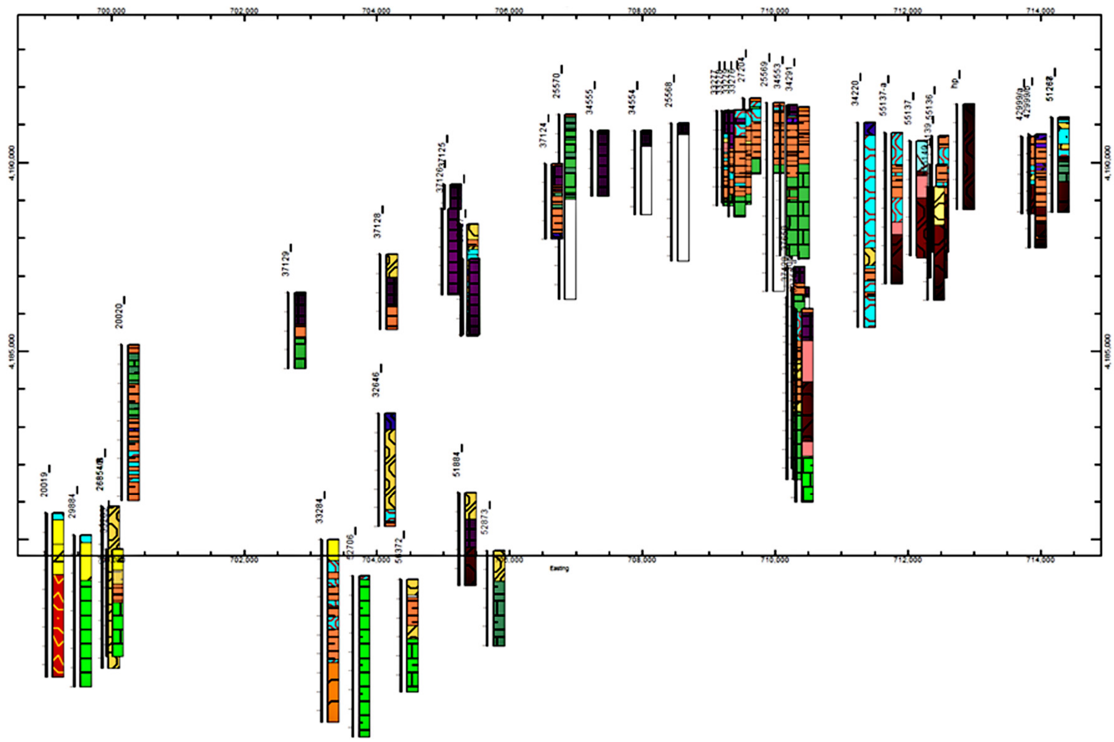


Fig. 1. Well's logs in the Kaklık aquifer and important two graben faults.

Table 5. Aquifer hydraulic parameters (T, S, Kf) estimated by Aqtesolv version 4.5.

| wells | T | S | b | K | L | dl | h | r | √Kf | v max | Q max | R | Qg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Transmissivity m2/day T=Kxb | Storage Coefficient | Aquifer Thicknes (m) | Hydraulic Conductivity (m/day) | Well depth (m) | Dynamic level Aq.top (m) | Dynamic level Aq.bot. (m) | Radius of well (m) | Hydraulic Conductivity (m/day) | Maximum Velocity m/s | Max. Long Term Discharge | Influence Radius (m) | General Discharge (m3/day) |
| 53114 | 68.93 | 1.6E-05 | 117.8 | 0.59 | 150 | 39.1 | 110.9 | 0.23 | 0.76 | 0.05 | 8.17 | 15879 | 261 |
| 51884 | 44.18 | 3.8E-08 | 100 | 0.44 | 122 | 55.7 | 66.3 | 0.23 | 0.66 | 0.04 | 4.24 | 67199 | 618 |
| 52706 | 61.94 | 4.6E-06 | 203.7 | 0.30 | 212 | 46.35 | 165.65 | 0.23 | 0.55 | 0.04 | 8.80 | 62976 | 1072 |
| 52758B | 764 | 5.9E-08 | 256 | 2.98 | 256 | 24.8 | 231.2 | 0.23 | 1.73 | 0.12 | 38.46 | 128529 | 8556 |
| 55137B | 145.5 | 3.9E-08 | 183.8 | 0.79 | 200 | 46.3 | 153.7 | 0.23 | 0.89 | 0.06 | 13.17 | 80343 | 1978 |
| 55136 | 74.13 | 4.6E-06 | 115.7 | 0.64 | 154 | 44.88 | 109.12 | 0.23 | 0.80 | 0.05 | 8.41 | 15847 | 268 |
| 55140 | 27.36 | 2.9E-06 | 105.9 | 0.26 | 130 | 60 | 70 | 0.23 | 0.51 | 0.03 | 3.43 | 54679 | 413 |
| 55139 | 32.73 | 2.9E-06 | 95.71 | 0.34 | 150 | 64.52 | 85.48 | 0.23 | 0.58 | 0.04 | 4.81 | 17947 | 177 |
| 52873 | 17.57 | 5.9E-08 | 103.8 | 0.17 | 126 | 28.8 | 97.2 | 0.23 | 0.41 | 0.03 | 3.85 | 8098 | 67 |
| 52759 | 41.89 | 7.3E-07 | 103.1 | 0.41 | 125 | 31.6 | 93.4 | 0.23 | 0.64 | 0.04 | 5.73 | 18549 | 215 |
| 53209 | 444.5 | 2.2E-08 | 132 | 3.37 | 150 | 31.45 | 118.55 | 0.23 | 1.84 | 0.12 | 20.95 | 74044 | 2810 |
| 51883 | 34.32 | 1.1E-05 | 121.1 | 0.28 | 140 | 45.55 | 94.45 | 0.23 | 0.53 | 0.04 | 4.84 | 42562 | 421 |
| 57022 | 939.8 | 5.8E-08 | 142.7 | 6.59 | 150 | 18.3 | 131.7 | 0.23 | 2.57 | 0.17 | 32.55 | 84688 | 4870 |
| 52198 | 7.849 | 5.9E-08 | 90 | 0.09 | 150 | 87.44 | 62.56 | 0.23 | 0.30 | 0.02 | 1.78 | 24310 | 99 |
| 56372 | 72.29 | 5.7E-08 | 71.48 | 1.01 | 148 | 96.7 | 51.3 | 0.23 | 1.01 | 0.07 | 4.97 | 60882 | 630 |
| 48775 | 102.9 | 2.2E-08 | 103.8 | 0.99 | 150 | 62.75 | 87.25 | 0.23 | 1.00 | 0.07 | 8.37 | 49434 | 802 |
| 51332 | 987.9 | 8.5E-08 | 97.84 | 10.10 | 110 | 15.32 | 94.68 | 0.23 | 3.18 | 0.21 | 28.97 | 30124 | 1637 |
| 51331 | 10.57 | 5.9E-08 | 96.87 | 0.11 | 110 | 14.64 | 95.36 | 0.23 | 0.33 | 0.02 | 3.03 | 1496 | 11 |
| 37128 | 3450 | DSI | 81.77 | 42.19 | 80 | 30 | 50 | 0.23 | 6.50 | 0.43 | 31.27 | 619086 | 37459 |
| 37129 | 1200 | DSI | 79.3 | 15.13 | 82 | 20 | 62 | 0.23 | 3.89 | 0.26 | 23.22 | 201893 | 8487 |
| 37658 | 1000 | DSI | 123.8 | 8.08 | 123.8 | 40 | 83.8 | 0.23 | 2.84 | 0.19 | 22.93 | 341052 | 14822 |
| 20020 | 9900 | DSI | 197.6 | 50.09 | 197.6 | 55 | 142.64 | 0.23 | 7.08 | 0.47 | 97.21 | 1167788 | 190649 |
| 25568 | 21000 | DSI | 178.6 | 117.56 | 178.6 | 45 | 133.63 | 0.23 | 10.84 | 0.72 | 139.52 | 1463748 | 331101 |
| 25569 | 14000 | DSI | 249.3 | 56.16 | 249.3 | 30 | 219.3 | 0.23 | 7.49 | 0.50 | 158.25 | 674443 | 166466 |
| 30691 | 1500 | DSI | 294.6 | 5.09 | 294.6 | 24 | 270.6 | 0.23 | 2.26 | 0.15 | 58.80 | 162466 | 16103 |
| 37124 | 5600 | DSI | 99.8 | 56.11 | 99.8 | 36 | 63.8 | 0.23 | 7.49 | 0.50 | 46.02 | 809007 | 68844 |
| 37125-b | 800 | DSI | 17.77 | 45.02 | 17.77 | 10 | 7.77 | 0.23 | 6.71 | 0.45 | 5.02 | 201290 | 2639 |
| 20275 | 24885 | DSI | 238.4 | 104.38 | 238.4 | 25 | 213.4 | 0.23 | 10.22 | 0.68 | 209.95 | 766261 | 246495 |
| 26854-b | 150 | DSI | 134.6 | 1.11 | 134.6 | 26 | 108.6 | 0.23 | 1.06 | 0.07 | 11.04 | 82341 | 1730 |
| 32648 | 145 | DSI | 149.4 | 0.97 | 149.4 | 40 | 109.4 | 0.23 | 0.99 | 0.07 | 10.38 | 118220 | 2399 |
| 32646 | 540 | DSI | 134.5 | 4.01 | 134.5 | 52 | 82.5 | 0.23 | 2.00 | 0.13 | 15.92 | 312579 | 10073 |
| 33283 | 115 | DSI | 114.8 | 1.00 | 114.8 | 15 | 99.8 | 0.23 | 1.00 | 0.07 | 9.62 | 45039 | 831 |

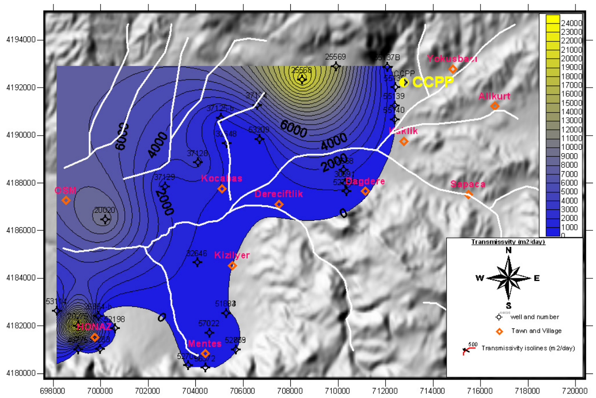


Fig. 2. Transmissivity distribution map.

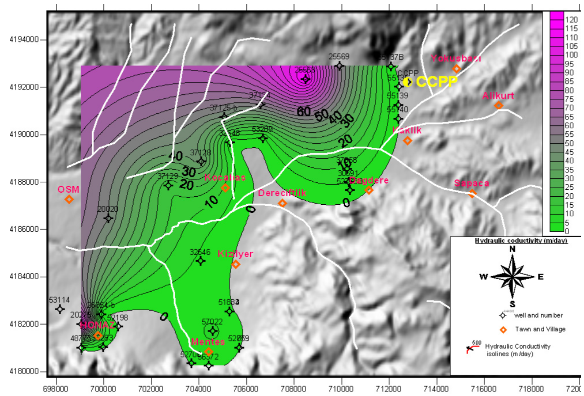


Fig. 3. Hydraulic Conductivity map (Kf).

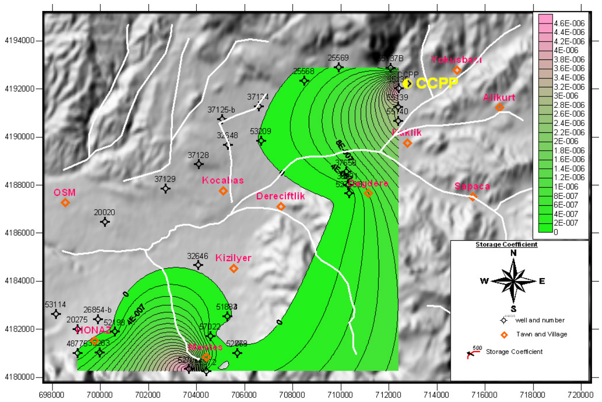


Fig. 4. Storage coefficient (S) map.

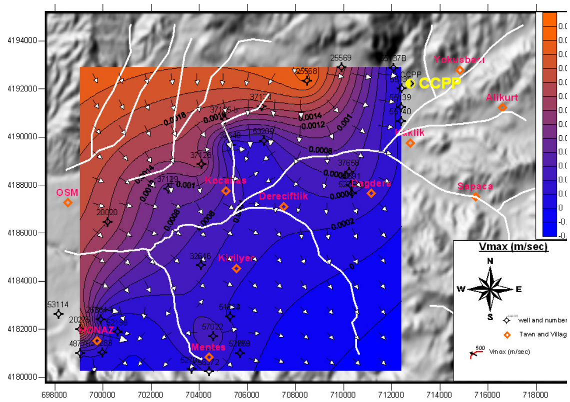


Fig. 5. $V_{max}$ values and flow directions.

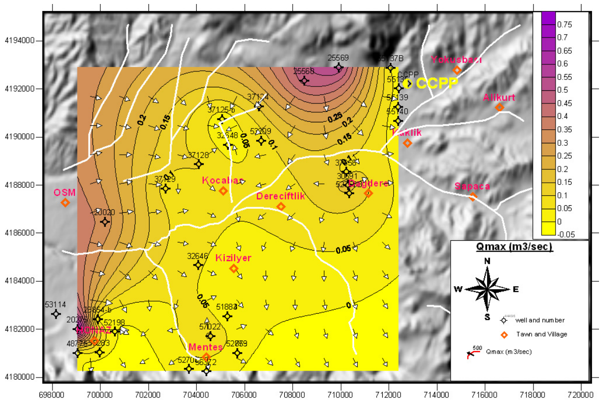


Fig. 6. Maximal long-term discharges, $Q_{max}$.

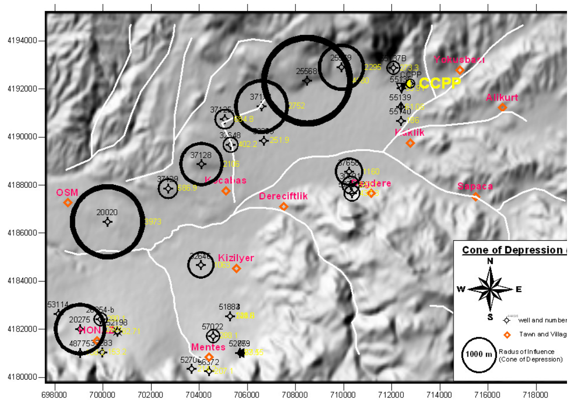


Fig. 7. Radius of influence in meters.

The estimation of aquifer hydraulic parameter was achieved by using the pumping tests data, which were taken from the DSI. Transmissivity -T, Storage Coefficient-S and Hydraulic Conductivities -Kf were estimated by using Aqtesolve v4.5 software (Duffield, G.M., 2008). The estimated hydraulic parameter of 36 wells is given in Table 5. the Theis (1935) method proposed for unconfined aquifer was used for 26 wells. For the other 10 wells, the Theis (1935) method proposed for confined aquifer was applied. The transmissivity contours in Figure 4 are drawn based on the estimated hydraulic parameter shown in Table 5 by using kriging method. Transmissivity values range between 133 and 267,300 $m^2$/day. Transmissivity contour map shows highest values wells of 25568, 33279, 33276, 33277 and 33278 near Kaklık Cave. These very high transmissivity values are the result of karstification in Çökelez Limestone, travertine and limestone layers of the Sazak formation and junction of graben fault systems at this region. At the Kaklık aquifer, transmissivity contours range between 10 and 24,885 $m^2$/day.

Based on the estimated hydraulic parameter as shown in Table 5 were drawn Hydraulic conductivity contours as m/day in Figure 5 by using kriging method. Hydraulic conductivity values range between 0 and 120 m/day. Hydraulic conductivity contour map shows highest values wells of 25568, 33279, 33276, 33277 and 33278 in vicinity of Kaklık Cave. These very high Hydraulic conductivity values is a result of Karstification in Çökelez Limestone, travertine and limestone layers of Sazak formation, and junction of graben fault systems at this region.

The storage coefficient (S) is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. Distribution map of Storage coefficient (S) of Kaklık aquifer was given in Table 5 and figure 6. The storage coefficient varies between $2x10^{-7}$ and $4.6\ x10^{-6}$. Highest storage coefficient is in the alluvium aquifers at the Menteş area. The rate of movement of groundwater is important in many problems, particularly those related to pollution. For example, if a harmful substance is introduced into an aquifer upgradient from a supply well, it becomes a matter of great urgency to estimate when substance will reach the well. The Maximum Velocity of movement of groundwater is calculated by using Sichardt (2000) method; Vmax = °Kf /15 = m/sec. Estimated Vmax values of groundwater in kaklık aquifer changes between 0-0.0026 m/sec (Table 5 and Figure 7).

The maximum long-term discharges, $Q_{max}$ ($m^3$/sec) is expressed as $Q_{max} = 2\pi$ r h °Kf /15,

where: - r, is the radius of well, h is dynamic water level, and Kf ist hydraulic conductivity.

The maximum long-term discharges, $Q_{max}$ is estimated in Table 5 and is shown in Figure 8. $Q_{max}$ values vary between 0 and 0.75 $m^3$/sec. The radius of influence of wells is estimated by using Sichardt method from the equation of R= 3000 (b-h) °Kf = meter. Radius of influence of wells in Kaklık aquifer is estimated in Table 1 and is shown in Figure 8. Radius of influence of wells located at north of the Kaklık aquifer is about bigger than 1 or 2 km.

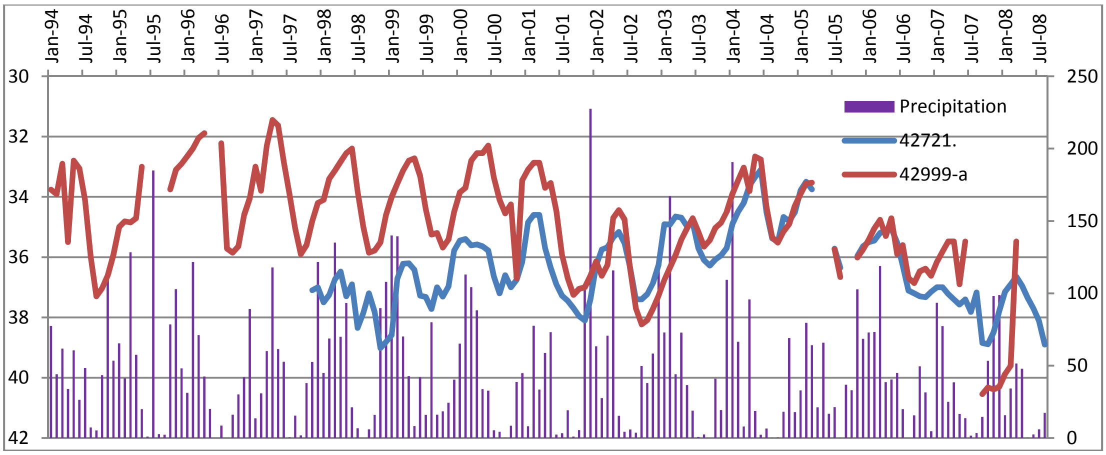


Fig. 8. Water table fluctuating in 42721 and 42999a from 1994 to 2008.

## 2.2. Groundwater

Kaklık aquifer in the upper Curuksu regions were drilled at least 69 deep wells by DSI. The groundwater observations were realized only 4 well by DSİ. These wells are 46978/A, 42999/A, 37628, and 37269.The long-term water level observations has been realized for the only 4 wells (42721, 42999a, 45192 and 42720) by DSI from 1994 year to 2008 year (Fig. 10). According to these data, the water table shows a decreasing of 4 m from 1995 (32 m) to 2003 (36 m) year. Water table in well of 42999a increases from 2003 to 2005 and decrease from 2005 to 2008 year again. The 42 721 wells show an increasing trend from 1998 to 2004 year and a decreasing trend from 2004 to 2008. However, the water table of 45192 shows a fluctuating of 1.5 m from 0.5 m to 2 m between years 1994- 2001. Water table of 42720 well shows an increasing from 1997 to 2004.

There are 12 irrigation cooperatives in the Curuksu basin base on DSI (2008) records. Sum of production wells is about 46, which are used to irrigation of 21645 ($km^2$) lands. Motopumps are working 26390 hours/year with 2066 liter/sec. Assignment reserve of all wells is $16.748 \times 10^6$ $m^3$/year. Three irrigation cooperative which are Kaklık, Sapaca and Yokuşbaşı, are located in the Kaklık aquifer. These three cooperatives have 14 production wells, which are used to irrigational purpose of 5200 $km^2$ land. Motopumps are working 7083 hours/year with 385 liter/sec. Assignment reserve of 3 irrigation cooperatives of wells is $3.243 \times 10^6$ $m^3$/year and only Yokuşbaşı is 0.664x106 $m^3$/year. Potentiometric surface maps for the years 2008, when was constructed the Kaklık aquifer and it shows the directions of groundwater flow. Potentiometric surface varies from 630 m at Alikurt (East) to 380 m OSM (west) in the flow path of 20 km (Fig. 11). Hydraulic gradient (h=dh/dl) is h= 250/20000= 0.0125. Flow directions generally incline from east to west.

## 3. Conclusion

Pumping tests realized for every well was used in order to investigate the well yields. Based on Well yields, the wells was classified for four categories. These categories are "Low well yield site" (flow rate varies 0-25 l/sec), "Middle well yield site" (flow rate varies 25-50 l/sec), "High well yield site" (flow rate varies 50-75 l/sec), "Very High well yield site" (flow rate varies 75-100 l/sec).

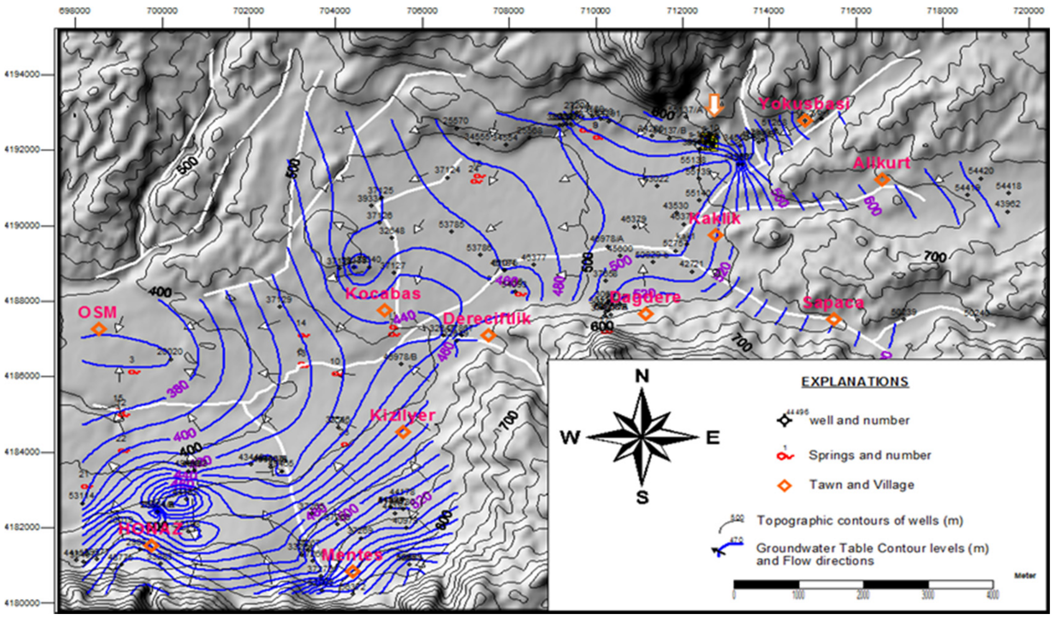


Fig. 9. Potentiometric surface map and groundwater flow directions in Kaklık aquifer.

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